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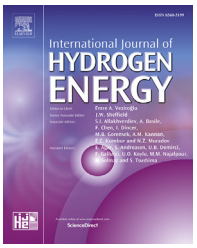

Thermal and electrochemical performance analysis of a proton exchange membrane fuel cell under assembly pressure on gas diffusion layer

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ABSTRACT

In this study, the effect of clamping pressure on the performance of a proton exchange membrane fuel cell (PEMFC) is investigated for three different widths of channel. The deformation of gas diffusion layer (GDL) due to clamping pressure is modeled using a finite element method, and the results are applied as inputs to a CFD model. The CFD analysis is based on finite volume method in non-isothermal condition. Also, a comparison is made between three cases to identify the geometry that has the best performance. The distribution of temperature, current density and mole fraction of oxygen are investigated for the geometry with best performance. The results reveal that by decreasing the width of channel, the performance of PEMFC improves due to increase of flow velocity. Also, it is found that intrusion of GDL into the gas flow channel due to assembly pressure deteriorates the PEMFC performance, while decrease of GDL thickness and GDL porosity have smaller effects. It is shown that assembly pressure has a minor effect on temperature profile in the membrane-catalyst interface at cathode side. Also, assembly pressure has a significant effect on ohmic and concentration losses of PEMFC at high current densities.

Introduction

Increase of fossil fuels consumption, limitation of fossil fuel resources and the environmental issues have made the fuel cell a suitable alternative for district power generation. Fuel cell is an electrochemical device that convert the chemical energy of fuel into electricity, directly. Proton exchange membrane fuel cells, also known as polymer electrolyte membrane fuel cells (PEMFC), are widely used due to the simple structure, relatively low manufacturing cost, high efficiency, low environmental pollution, long lifetime and low operating temperature [1]. The main components of fuel cell includes a five-layer structure that is known as membrane electrode assembly (MEA). MEA consist of a proton exchange membrane that is made of a thin layer of catalyst on both sides and a GDL in contact with each catalyst layer [2].

Fabrication process of fuel cells causes assembly pressure from bipolar plates (BPP) to GDL that affects the performance of the cell, considerably. An appropriate level of clamping pressure is required to provide adequate gas sealing and to reduce contact resistance between membrane and GDL [3]. However, excess pressure causes over-compression of membrane and GDL [4]. This effect should be well studied to

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achieve optimum assembly pressure. Wang et al. [5] evaluated the effect of assembly pressures on the through-plane electric resistance of a PEMFC, and they optimized the assembly pressure in order to achieve the best performance of the cell. They only considered anode side to simulate the electric resistance. Their results indicate that the clamping pressure of 1 MPa is the best assembly condition considering contact resistance and electric resistance in the through-plane between GDL and BPP. Qiu et al. [6] applied the continuous equivalent model to predict contact pressure field on the GDL. Their results revealed that the proposed mode is effective for evaluating assembly design, however, some parameters such as the gas flow resistance and the failure of GDL during the assembly were not considered. Moreover, the potential gradient and the bending of endplate between the interfaces of GDL-rib were ignored. Bates et al. [7] carried out experimental and simulation studies of assembly pressure on the performance of a PEM fuel cell stack. They used a 16-cell stack in experiments and the range of clamping pressure on the GDL was between 0 and 2.5 MPa. The simulation results had a good agreement with experimental data. They found that stress near the center of the stack is higher than near the endplates. In addition, they found that pressure distribution toward GDL center develops by applying a load.

Numerous models have been evaluated to take into account the multi-physical processes in PEMFC such as electrochemical reactions, mass transfer of water and gas, etc., but the effects of assembly pressure are not considered in these models. Assembly pressure causes stack compression that leads to deformation of the GDL, and it has a significant effect on the durability and the performance of PEMFC. Therefore, investigation of GDL deformation is of high importance [8].

Several studies have been presented on the effect of assembly pressure in PEMFC. Zhou et al. [9] carried out a comprehensive analysis on the effects of assembly pressure, humidity, and operating temperature on the performance of PEMFC. The results of their study reveal that due to assembly pressure, the performance of PEMFC degrades but the overall performance of fuel cell system improves when the operating temperature and humidity increase. In a numerical analysis by Taymaz et al. [10], it is founded that contact resistance, porosity and GDL thickness decrease when the assembly pressure increases. In another research, Lai et al. [11] studied the effect of dimensional changes of fuel cell components on temperature distribution and hydration cycles. Moreover, they applied a finite element method to investigate the compression of MEA and GDL over the channel area. They reported that at higher transverse shear modulus of GDL, the compression over channels decreases. Norouzifard et al. [12] proposed an analytical model to investigate the mechanical behavior of GDLs under clamping force. Their results show that bending of carbon fibers is the main reason of GDL deformation. Lee et al. [13] studied the effect of GDL contraction on the performance of a PEMFC and proposed a correlation between the bolting torque of assembly and performance of PEMFC. They evaluated three types of GDLs under operating pressure of 1–7 MPa and operating temperature of 353 K. Their results indicate that better performance is achieved when less torque is applied, because at higher bolt torques the GDL is damaged. Also, they founded that by increase of GDL contraction, the performance of PEMFC degrades. Ge et al. [14] studied the effect of compression on the performance of PEMFC. They used two different GDL materials including carbon cloth double-sided ELAT and TORAY™ carbon paper. According to their results, an optimum compression ratio exists at low current densities that leads to the best performance of PEMFC. Zhou et al. [15] reported that the highest power density of PEMFC is achieved in an optimum clamping force. They showed that at higher clamping forces the porosity of GDL decreases and it leads to increase of gas transport resistance and decrease of PEMFC efficiency. In another study, Zhou et al. [16] proposed a mathematical model to evaluate the performance of PEMFC under assembly force for different GDLs. It is shown that by exerting assembly pressure, the thickness of GDL decreases and it causes more water content in the GDL and better cell performance, however, it leads to deterioration of the cell performance, simultaneously, due to reduction of GDL porosity.

Shi et al. [17] investigated the effect of compression of bipolar plates (BPP) faces on the performance of PEMFC. Their results reveal that oxygen concentration on cathode side decreases after exerting assembly force. Chippar et al. [18] performed a numerical simulation on the effects of non-uniform compression on the performance of PEMFC. Their results show that compression has a significant effect on important parameters including oxygen concentration, membrane water content, and current density distribution. They concluded that by decreasing the porosity of GDL due to compression, the amount of water accumulation in GDL increases. Yablecki et al. [19] modeled the effect of assembly pressure on the thermal resistance of PEMFC. Their results show that decrease of the GDL thickness leads to lower effective thermal conductivity as long as bulk porosity remains constant.

Although the effect of assembly pressure on the performance of PEMFC has been investigated in the literature, but its simultaneous effects on intrusion of GDL into the flow channel, GDL porosity and GDL thickness have not been studied so far. Moreover, previous studies are focused on only cathode side. In this regard, the new contribution of the present research is to investigate the effect of assembly pressure on different parameters of GDL in a PEMFC with three different geometries. The present model includes the entire area of the cell, i.e. both cathode and anode sides. For this purpose, deformation of GDL is analyzed using a finite element model, and the results are applied as an input to a computational fluid dynamic code to study the fuel cell electrochemical processes. Another novelty in this research is the non-isothermal condition that is considered in numerical solution of the momentum, mass, energy, and species conservation equation. This consideration is due to the fact that the temperature has a significant effect on the performance of the PEMFC.

Model description

In order to reduce the size of the computational domain, a single cell of PEM stack is modeled using finite element method. Since the length of the channel is relatively larger

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